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Implicit encoding of extrinsic object properties in stored representations mediating recognition: Evidence from shadow-specific repetition priming

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ABSTRACT

This study investigated whether, and under what conditions, stored shape representations mediating recognition encode extrinsic object properties of sensory input that vary according to viewing conditions. This was examined in relation to cast shadow. Observers (N=90) first memorised a subset of 3D multi-part novel objects from a limited range of viewpoints rendered with either no shadow, object internal shadow, or both object internal and external (ground) plane shadow. During a subsequent test phase previously memorised targets were discriminated from visually similar distractors across learned and novel views following brief presentation of a same-shape masked prime. The primes contained either matching or mismatching shadow rendering from the training condition. The results showed a recognition advantage for objects memorised with object internal shadow. In addition, objects encoded with internal shadow were primed more strongly by matching internal shadow primes, than by same shape primes with either no shadow or both object internal and external (ground) shadow. This pattern of priming effects generalised to previously unseen views of targets rendered with object internal shadow. The results suggest that the object recognition system contains a level of stored representation at which shape and extrinsic properties of sensory input can be conjointly encoded. Here, this is shown by the conjoint encoding of shape and object internal shadow. We propose that this occurs when cast shadow cannot be discounted during perception on the basis of external cues to the scene lighting model.

Word count = 239

One of the most remarkable aspects of human vision is our ability to recognize three-dimensional objects across variations in sensory input (e.g., Harris, Dux, Benito & Leek, 2008; Leek, 1998a; 1998b; Leek, Atherton & Thierry, 2007; Leek & Johnston, 2006). Object recognition is presumed to require the computation of a perceptual description of object shape from sensory input and the subsequent matching (or indexing) of this percept to a stored shape representation held in long-term memory (e.g., Davitt, Cristino, Wong & Leek, 2014; Edelman, 1999; Hummel, 2013; Marr & Nishihara, 1978). A fundamental issue concerns the structure and content of these stored shape representations. In ontological terms (e.g., Lewis, 1983) some properties of the sensory input may be regarded as *intrinsically* associated with object identity such as shape, texture, scale (and possibly colour). In contrast, other properties are only *extrinsically* associated with object identity such as shadow, shading, brightness and reflectance. These extrinsic properties are dependent on viewing conditions (e.g., scene structure, luminance direction and intensity). This distinction between intrinsic and extrinsic properties is very relevant to theories of object recognition. While it is generally assumed that intrinsic properties are stored at some level of stored representation as part of object knowledge, whether and under what conditions, extrinsic properties of sensory input are also encoded in these representations is less clear.

Central to this issue is that current theories of recognition make different claims about the abstractness of stored shape representations (Hummel, 2013). Some models allow for the conjoint encoding of shape and extrinsic features in image-based templates (Riesenhuber & Poggio, 1999; Serre, Oliva & Poggio, 2007; Tarr & Bülthoff, 1995). These can be contrasted with structural description models in which extrinsic properties of sensory input must be discounted during perceptual processing, and thus not encoded in stored shape representations (e.g., Biederman, 1987; Hummel & Biederman, 1992; Leek et al., 2005; Marr & Nishihara, 1978). In this study we examine this issue in relation to the encoding of extrinsic information about shape that is related to cast shadow - which we use as a case in point.

Cast shadow is a ubiquitous property of natural scenes, and arises from the occlusion of light by one surface or object upon another, which can be cast onto another surface of the occluding object, the surface of a different object or the ground (e.g., Casati, 2004; Elder, Trithart, Pintilie & MacLean, 2004; Knill, Mamassian & Kersten, 1997; Mamassian, Knill & Kersten, 1998). Here we distinguish between cast shadow that is attached to the surfaces of an object which we refer to as ‘*object internal shadow*’), and shadow that is cast across a ground plane on which the object rests (which we refer to as ‘*object external shadow*’) - (see Figure 1)[1]. Cast shadow can create spurious edge boundaries, and is dependent on surface reflectance properties, ambient lighting and source direction (i.e., the lighting model) as well as scene content, organisation and structure. Even so, there is evidence that, when combined with other assumptions about the scene lighting model (e.g., the ‘light from above’ prior), shadow (and shadow) can provide useful information that facilitates the perceptual interpretation of 3D shape (e.g., Aubin & Arguin, 2014; Castiello, 2001; Cavanagh & Leclerc, 1989; Dee & Santos, 2011; Enns & Rensink, 1990; Kleffner & Ramachandran, 1992; Knill et al., 1997; Mamasian, Knill & Kersten, 1998; Madison, Thompson & Kersten, 2001; Ramachandran, 1988). At the same time, there is empirical evidence supporting the existence of a shadow discounting mechanism in perception (Rensink and Cavanagh, 2004). From a computational perspective this makes sense as one might suppose that shadow (like other extrinsic properties of sensory input) is ultimately discounted to facilitate indexing a stored (shadow-invariant) shape representation.

[1] Cast shadow can also be distinguished from attached shadow and shading (e.g., Mamassian, Knill & Kersten, 1998. However, all can be defined as extrinsic properties of sensory input for the purposes of the present study. We restricted our investigation to cast shadow (including internal attached shadow). Shading was held constant across conditions.

Previous studies do not provide clear evidence on this issue. In a seminal paper, Tarr, Kersten and Bülthoff (1998) presented a series of studies in which observers matched the shape of sequentially presented, masked, 3D surface-rendered novel objects under the same or different lighting conditions. The results showed that perceptual matching was less efficient for same shape stimulus pairs when the lighting/shadow was different compared to when it was identical - consistent with the hypothesis that shadow can assist the perceptual recovery of object shape. In another experiment the status of cast shadow in stored object representations was examined. Observers first memorised a sub-set of novel objects rendered with object internal shadow, and they were then asked to identify the same objects from learned and novel viewpoints with either the same or a different shadow rendering. The results were equivocal. Whilst there was some evidence that performance was better for recognition of targets rendered with the same shadow shown in the training phase, this was only found in two out of five analyses. Furthermore, more recent evidence reported by Braje, Legge and Kersten (2000) based on the naming of common objects failed to find evidence for shadow-specific encoding in a task in which observers named blurred or un-blurred photographic images of fruits and vegetables with or without cast shadow. Thus, current evidence about whether stored representations encode object extrinsic properties like shadow remains inconclusive.

While shadow can (at least under some conditions) facilitate the perceptual interpretation of 3D object structure (e.g., Cavanagh & Leclerc, 1989; Kleffner & Ramachandran, 1992; Knill et al., 1997; Ramachandran, 1988), we might hypothesise that the likelihood of object internal shadow being bound within a stored shape representation to depend on the extent to which it can be distinguished from shape during perceptual processing. One potentially important cue that facilitates the segmentation of shape from both internal and external shadow is knowledge about the scene lighting model, and the dispersion of light along the ground plane (see Figure 1). Thus, the availability of cues to the external lighting model from ground plane shadow may play a key role in determining whether or not shape and object internal shadow are conjointly encoded in stored object representations.

The current study was designed to test this hypothesis. Unlike any previous study, we used a repetition priming paradigm (e.g., Arguin & Leek, 1993) to assess the implicit processing of object shadow during a recognition memory task. To do this we created a set of surface rendered novel 3D objects in order to precisely control observer familiarity (with both object shape and viewpoint). Different groups of observers were trained to identify a sub-set of these objects at three viewpoints under three different lighting conditions: no shadow, object internal shadow only, and both object internal and external shadow. During a subsequent test phase targets were shown at previously trained and novel viewpoints and discriminated from visually similar distractors. On some trials targets were preceded by a brief masked same-shape prime containing either matching or mismatching shadow rendering from the learning condition. We predicted that if object internal shadow is encoded in the stored representations mediating recognition we should observe priming between same shape prime-target pairs that contain the same object internal shadow rendering. In addition, if the binding of object internal shadow and shape depends on the availability of external cues to scene lighting derived from external ground shadow, then object internal shadow-specific priming should only occur in the absence of ground shadow cues.

METHOD

Participants

90 students from Bangor University (Mean age = 21.13 years; *SD* = 5.08; 10 left handed) participated in the study for course credit. All participants had normal or corrected to normal visual acuity. Thirty participants were randomly assigned to one of three learning conditions (defined below): No Shadow: Mean age = 22.45 years; *SD* = 3.22; 4 left handed; Object Internal Shadow: Mean age = 20.13; *SD* = 3.25; 2 left handed; Object Internal and External Shadow: Mean age 20.5 years; *SD* =3.22; 4 left handed). The experimental protocol was approved by the Ethics Committee of the School of Psychology in accordance with the Ethics Guidelines of the British Psychological Society. Informed consent was obtained from all participants.

Stimuli

The stimuli were 24 3D novel objects each comprising four volumetric parts. The stimuli were divided into two sets of 12 objects with items in Set 1 each having one visually similar counterpart in Set 2 created by arranging the same component parts in a different spatial configuration (see Figure 2). The component parts were uniquely defined by variations among non-accidental properties (NAPs) comprising of straight or curved edges, symmetry of the main axis, co-linearity, and parallelism (Biederman, 1987).

INSERT FIGURE 1 ABOUT HERE

The object models were produced using Strata 3D software (Strata, USA) and rendered using ray tracing with a mustard yellow colour (RBG: 233, 190, 33), and scaled to fit a 900 x 900 pixel frame. Stimuli subtended approximately 16° of visual angle from a viewing distance of

60 cm. Separate versions of each stimulus were made at six viewpoints via rotated of 60° increments around a vertical axis.

INSERT FIGURE 2 ABOUT HERE

The 0°, 120° and 240° rotations were designated as training views, with 60°, 180° and 300° rotations as test views. For each stimulus and viewpoint three different variants were created. Each set was modelled with a single uniform light source in the upper left hand quadrant: No Shadow – which were rendered without the cast shadow being drawn; Object Internal Shadow – which were rendered with internal cast shadow; Object Internal and External Shadow which were rendered with internal cast shadow and external shadow on an inferred ground plane (see Figure 2b). Stimuli in all conditions were shown with shading in order to preserve the consistency, and naturalness, of the rendering. The actual ground plane was not shown to avoid adding additional scene detail to one condition which would invalidate comparisons across conditions. A version of each stimulus was created to serve as a prime. Primes were rescaled to 75% of the original size to avoid direct pixel-to-pixel correspondence when shown in the trial sequence of the test phase (see below).

Apparatus

Stimuli were presented using E-Prime software (Psychology Software Tools Inc.) on a 17” monitor with a screen resolution of 1280 x 960 pixels. A chin rest maintained the participants at 60cm from the screen.

Design and Procedure

A 2 (View $_{WS}$: Training, Test) x 3 (Prime Type $_{WS}$: No Shadow, Object Internal Shadow, Object Internal and External Shadow) x 3 (Learning Group $_{BS}$: No Shadow, Object Internal Shadow, Object Internal and External Shadow) mixed design. The experiment consisted of a learning phase and a test phase. During the learning phase, each participant memorised four targets randomly drawn from Set 1 from three different viewpoints (0°, 120°, and 240°). Each target was presented twice at each viewpoint (N trials = 24) for an unlimited duration. Memorisation accuracy was assessed via a post-training verification task involving the computer presentation of a single item (target or non-targets which were not used in the test phase), and required an untimed target/non-target keyboard response. Feedback was provided after each trial. Targets and non-targets were presented at each of the three training viewpoints and continued until a criterion level of 80% accuracy had been achieved.

The test phase comprised 192 trials divided into two equal blocks of 96 trials each. Across blocks there were 96 target trials and 96 non-target trials. For targets there were 24 trials for each of the three priming conditions (No Shadow; Object Internal Shadow; Object Internal and External Shadow). All primes matched in shape the subsequent target, but varied in illumination match depending on the training condition. There were also 24 no prime target trials which served to provide a baseline measure for repetition priming. The 3 learned and 3 novel views were probed 16 times each across target trial blocks. The non-target trials showed distractor items (i.e., non-target objects from the 24 items stimulus set). All non-target trials were preceded by a same shape prime (so that prime-target shape relatedness was not predictive of target identity). The six viewpoints were presented with equal frequency (N = 16 trials per view). Prime viewpoint always matched that of the following stimulus. Trial order was randomised within blocks.

Each test phase trial began with a fixation cross (750ms), a blank ISI (500ms) and a prime (250ms). Following prime offset and a further blank ISI (100ms), a mask was shown (250ms) followed by a blank ISI (200ms). The target/non-target was then presented until response. Participants pressed ‘k’ if they recognised the object from the learning phase or ‘d’ if they did not. Response time (RT) and accuracy data were collected as dependent measures.

Feedback on response accuracy was provided after each trial. Participants were told that their task was to recognise the target objects they had memorised during the learning phase, and that they were to respond as quickly and accurately as possible. The test phase lasted approximately 45 minutes.

Statistical Analyses

An a priori significance level of .05 was adopted. Exact p values are shown, except where p < .001. Measures of ANOVA main effect sizes in terms of η^2 are reported where applicable.

RESULTS

Analyses of accuracy and sensitivity (d')

Table 1 shows the mean percentage correct responses per learning condition for target and non-target trials, together with the d' measure of sensitivity[2]. Mean accuracy was 90.53% (SE = 0.01) for target trials, and 86.87% (SE = 0.01) for non-target trials. A 2 (Target, Non-Target) x 3 (Learning Group: No Shadow, Object Internal Shadow, Object Internal and External Shadow) ANOVA found a significant main effect of Target, F (1, 28) = 15.28, p = .001, η^2 = .353. There were no other significant main effects or interactions.

INSERT TABLE 1 ABOUT HERE

A one-way ANOVA across training conditions using d' was not significant (F (2, 88) = 2.44, p =.092ns).

[2] The data from one participant in the internal object shadow learning group were excluded from all analyses due to difficulties engaging with the task resulting in an error rate > 3 SDs from the condition mean.

Analyses of RTs

Trials with incorrect responses (9.47% of trials) were excluded from the RT analyses.

Preliminary analyses of priming effects (target trials)

Our first goal was to examine whether the priming manipulation affected subsequent target recognition in order to establish that shape and shadow information in the primes was processed. Figure 3 shows the mean RTs for prime and no-prime target trials as a function of prime type and learning condition.

INSERT FIGURE 3 ABOUT HERE

Overall mean RTs were faster for prime (*M* =892.66ms; *SD* = 542.94) than no prime trials (*M* = 1250.81ms; *SD* = 554.93); *t* (88) = 14.53; *p* <.001. A one-way ANOVA of the priming effects (Mean RT prime/condition-Mean RT no-prime) across learning groups was significant, *F* (2, 88) = 4.01, *p* =.022. The priming effect (collapsed across prime type) was larger for Object Internal Shadow targets (M = 579.97ms; SD = 302.40) compared to both No Shadow (*M* = 232.07ms; SD = 657.13; *t* (57) = 2.63, *p* = .01) and Object Internal and External Shadow targets (*M* = 262.38ms; SD = 558.87; *t* (57) = 2.70, *p* = .009). The mean priming effects for the No Shadow versus Object Internal and Object Internal and External targets were not significantly different (*t* (58) = -0.19, *p* = .8).

Further analyses were also conducted on mean RTs for the no prime trials. A one-way ANOVA on these data across the three learning groups was significant, *F* (2, 88) = 4.24, *p* =.018. Planned comparisons showed significant differences in mean RTs for no prime for Object Internal Shadow vs. Object Internal and External Shadow trials; *t* (28) = 2.95, *p* = .006; and for Object Internal shadow vs. No Shadow trials, *t* (28) = 2.04, *p* = .05. There was no significant difference between No Shadow vs. Object Internal and External Shadow, t (29) = -.847, p = .40.

These analyses show that the task elicited robust priming effects and that targets encoded during the learning phase with object internal shadow showed the largest prime-related benefit. In contrast, primes containing object internal and external shadow elicited no greater priming than no shadow primes. Comparisons across no prime trials showed a recognition advantage for stimuli memorised with object internal shadow.

Analyses of prime type, learning group and viewpoint

The following analyses focussed on mean RTs for the primed target trials to explore the implicit encoding of shadow as a function of prime type and learning condition. A 3 (Prime Type: No Shadow, Object Internal Shadow, Object Internal and External Shadow) x 2 (View: Learned, Novel) x 3 (Learning Group: No Shadow; Object Internal Shadow, Object Internal and External Shadow) mixed ANOVA found significant main effects of View, F (1, 28) = 11.54, p = .002, η^2 = .292., indicating that mean RTs for learned views (M = 865.64ms; SD = 300.88) were faster than for novel views (M = 925.98ms; SD = 332.35). There was also a significant main effect of Learning Group F (2, 56) = 3.80, p = .028, η^2 = .120, with mean RTs for the Object Internal Shadow Group (M = 668.34ms; SD = 302.40) faster than both the No Shadow (M = 1016.24ms; SD = 118.15; t (57) = -2.63, p < .001) and Object Internal and External Shadow Group (M = 985.93; SD = 102.05; t (57) = -2.70, p = .005). Planned contrasts for each learning group showed that for the Object Internal Shadow Group mean RTs were significantly faster on Object Internal Shadow prime trials compared to both No Shadow prime, t (28) = -4.56, p < .001, and Object Internal and External Shadow prime trials, t (28) = -2.86, p < .008 (see Figure 3). There were no significant differences in mean RTs for either the No Shadow and Object Internal and External Shadow training groups across prime types. Additional analyses of RT data for the Object Internal Shadow Group were run to examine the effects of viewpoint.

A 2 (View: Learned, Novel) x 3 (Prime Type: No Shadow, Object Internal Shadow, Object Internal and External Shadow) repeated measures ANOVA showed a significant main effect of Prime type, F (2, 56) = 10.15, $p < .0001$, $\eta^2 = .266$, but no main effect of View and no interaction.

Analyses of RTs (non-target trials)

A 3 (Learning Group: No Shadow; Object Internal Shadow, Object Internal and External Shadow) x 3 (Prime Type: No Shadow, Object Internal Shadow, Object Internal and External Shadow) mixed ANOVA showed a significant main effect of Learning Group, F (2, 86) = 4.10, $p = .019$, $\eta^2 = .74$. RTs for Object Internal Shadow stimuli (M = 609.27ms, SD = 273.48) were faster than for both No Shadow (M = 921.96ms, SD = 561.51, t (28) = 2.13, $p = .04$) and Object Internal and External Shadow (M = 890.65ms, SD = 490.52, t (28) = 2.15, $p = .04$). RTs for No Shadow and Object Internal and External Shadow non-target stimuli were not significantly different. There was no main effect of Prime Type.

GENERAL DISCUSSION

The results showed several key findings: First, analyses of responses to un-primed and primed trials showed a recognition advantage for objects memorised with object internal shadow over the same shapes memorised with either no shadow or both object internal and external shadow. Second, targets memorised with object internal shadow were primed more strongly by (same shape) object internal shadow primes, than by either no shadow or object internal and external shadow same-shape primes. Third, the same pattern of priming effects for object internal shadow objects was found for targets presented at previously seen and novel views.

These results provide new evidence that, under some conditions, object recognition is mediated by stored shape representations that encode extrinsic properties of sensory input related to object internal shadow (Tarr et al., 1998). This follows from the observation of shadow-specific priming for objects with internal cast shadow. Specifically, we found that objects memorised with internal shadow were primed more effectively by same-shape primes with matching internal shadow than by same-shape primes with either no shadow or both internal and external (ground plane) shadow. This finding is of theoretical relevance to models of object recognition because it sheds light on the properties of stored representations that mediate shape identification. In particular, the findings are consistent with appearance-based models that allow for the conjoint encoding of shape and image properties that are specific to the viewing conditions (e.g., Riesenhuber & Poggio, 1999; Serre, Oliva & Poggio, 2007), as well as with so-called ‘hybrid’ or ‘dual coding’ accounts that posit both image-based and structural description representations (e.g., Hummel, 2001; Hummel & Stankiewicz, 1996; Foster & Gilson, 2002). Here we showed that this extends to object extrinsic properties of sensory input related to internal cast shadow.

We also found that objects learned with internal cast shadow were recognised more quickly than those learned with either no shadow or with both internal and external shadow. This advantage was found for both primed and un-primed targets, and for non-targets rendered with object internal shadow. This advantage is consistent with evidence from other studies that shadow may facilitate the perceptual processing of object shape (e.g., Cavanagh & Leclerc, 1989; Kleffner & Ramachandran, 1992; Knill et al., 1997; Ramachandran, 1988). The encoding of object internal shadow in stored representations – as shown in the current study by greater priming for same shape prime-target pairs with object internal shadow, further suggests that shadow can facilitate recognition. This may be because shadow, when encoded in stored representations, provides additional information about internal image contrast, texture or surface markings. However, an additional key finding was that objects learned with both internal and external (ground) shadow did not show a similar advantage over no shadow targets. This appears to show a boundary condition on shadow-specific priming. An explanation for this result is that when both internal and external shadow are present during the formation of a stored shape representation (i.e., during the learning/training phase), the perceptual system is able to discount internal cast shadow information early in the perceptual processing of the stimulus so that it is not encoded in a stored shape representation (Rensink & Cavanagh, 2004). Thus, the presence of ground shadow may provide a cue to the extrinsic scene lighting model that facilitates the perceptual segmentation of shape and shadow. In contrast, in the absence of ground shadow – or other cues to scene lighting, reliable early perceptual segmentation of shape and internal shadow may be more difficult increasing the likelihood that both are encoded in a stored shape representation. Consistent with this interpretation was the observation of equivalent recognition latencies (in both prime and no-prime trials) for targets encoded with no shadow and those with both object internal and external shadow. This finding helps to account for the data reported by Braje et al (2000). In their study observers named pictures of fruits and vegetables with or without shadow, and no shadow-specific effects were found. Such objects are highly familiar to most observers, and are likely to have been viewed in a variety of different scene and lighting contexts. This is likely to arise because stored shadow information may subsequently be discarded when objects have been seen under different viewing conditions of varying scene lighting and viewpoint.

We also found that the pattern of shadow-specific priming related to object internal shadow generalised to novel views – that is, to views of memorised objects that had not previously been seen in the training phase, and for which (by hypothesis) there is no stored image-based representation. At first glance this finding appears to be inconsistent with the hypothesis advanced here of conjoint encoding of shape and internal cast shadow in stored object representations. A similar result was also reported by Tarr et al (1998). They interpreted this finding in their data as support for the hypothesis that shape and shadow are not conjointly bound, but that image-based representations of shape are associatively linked to an extrinsic scene lighting model. On this account, the scene lighting model may be used to facilitate the segmentation of shape and of cast shadow bound to object surfaces during perception. However, another possibility is that the apparent generalisation of shadow-specific priming to novel views reflects the operation of a view generalisation mechanism based on interpolation from stored viewpoint- (and shadow) specific image-based templates (e.g., Bülthoff & Edelman, 1992). On this account, shadow-specific priming of novel views could derive from the summation of activation of partially overlapping shadow information encoded in the stored representations of familiar views. Current evidence does not allow us to distinguish between these two accounts.

In summary, we examined whether cast shadow, as an extrinsic sensory property of objects, is encoded in the stored representations of shape that mediate recognition. A repetition priming paradigm was used in which same shape prime-target pairs could have different

shadow rendering, or match in terms of no shadow, object internal shadow only, or both object internal and external (ground) shadow. The results showed a recognition advantage for objects memorised with object internal shadow. In addition, objects encoded with internal shadow were primed more strongly by matching internal shadow primes, than by same shape primes with either no shadow or both object internal and external (ground) shadow. This pattern of priming effects generalised to previously unseen views of targets rendered with object internal shadow. The results suggest that the object recognition system contains a level of stored representation at which shape and extrinsic properties of sensory input can be conjointly encoded. Here, this is shown by the conjoint encoding of shape and object internal shadow. We propose that this occurs when cast shadow cannot be discounted during perception on the basis of external cues to the scene lighting model.

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FIGURE LEGENDS

Figure 1 Illustration of the contrast between object rendering with no shadow, object internal shadow only, and both object internal and external shadow.

Figure 2 The stimulus set of 24 novel objects used in the current study. Targets were selected from the upper set of 12 objects.

Figure 3 Mean RTs for primed target trials as a function of prime type and learning condition, and for no prime trials. Bars indicate standard error of the mean. * indicates significant differences.

Table 1 Mean accuracy (% correct) and d' (SE) for target and non-target trials for each of the learning conditions**.**

Learning Group	Target		Non-Target			
	% Correct	(SE)	% Correct	(SE)	d'prime	(SE)
No Shadow	88.1	(0.02)	84.18	(0.02)	3.04	(1.24)
Internal Shadow	92.2	(0.01)	87.60	(0.02)	2.88	(1.21)
Internal and External Shadow	91.2	(0.01)	88.85	(0.01)	3.05	(1.18)

FIGURE 1

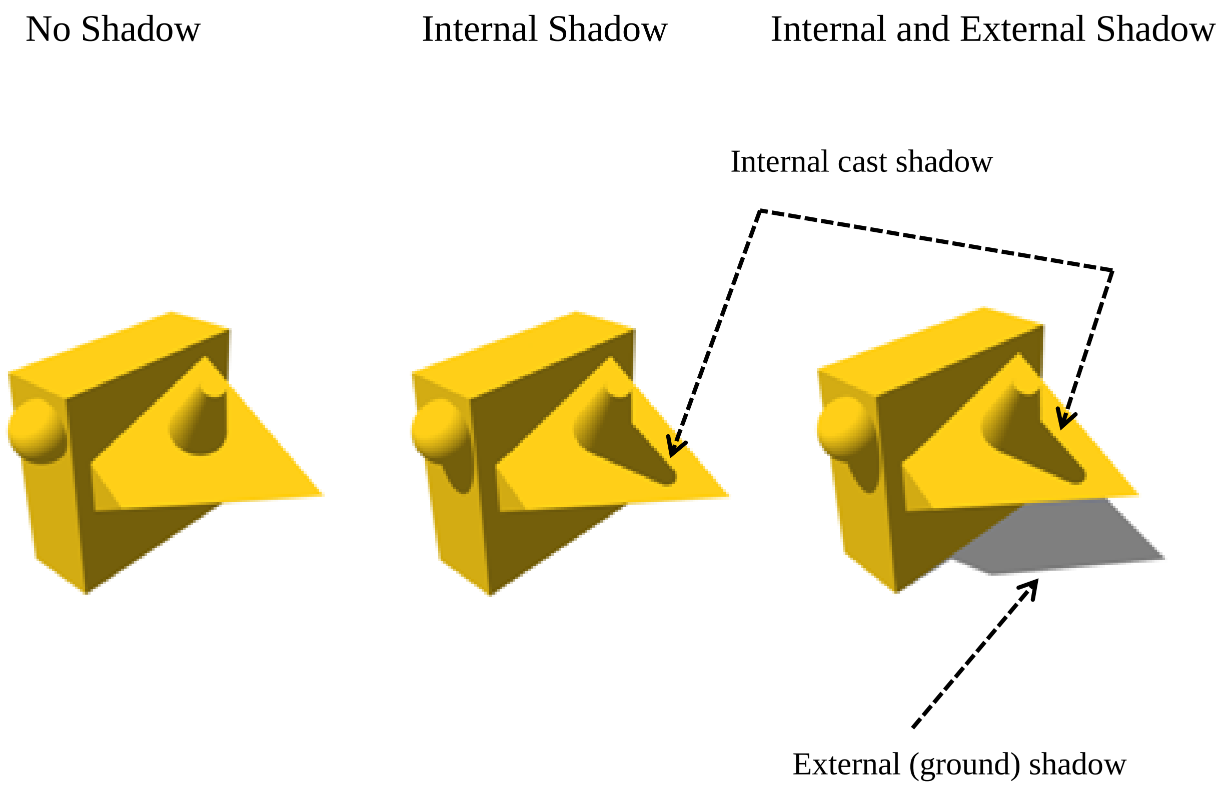

No Shadow
Internal Shadow
Internal and External Shadow
Internal cast shadow
External (ground) shadow

FIGURE 2

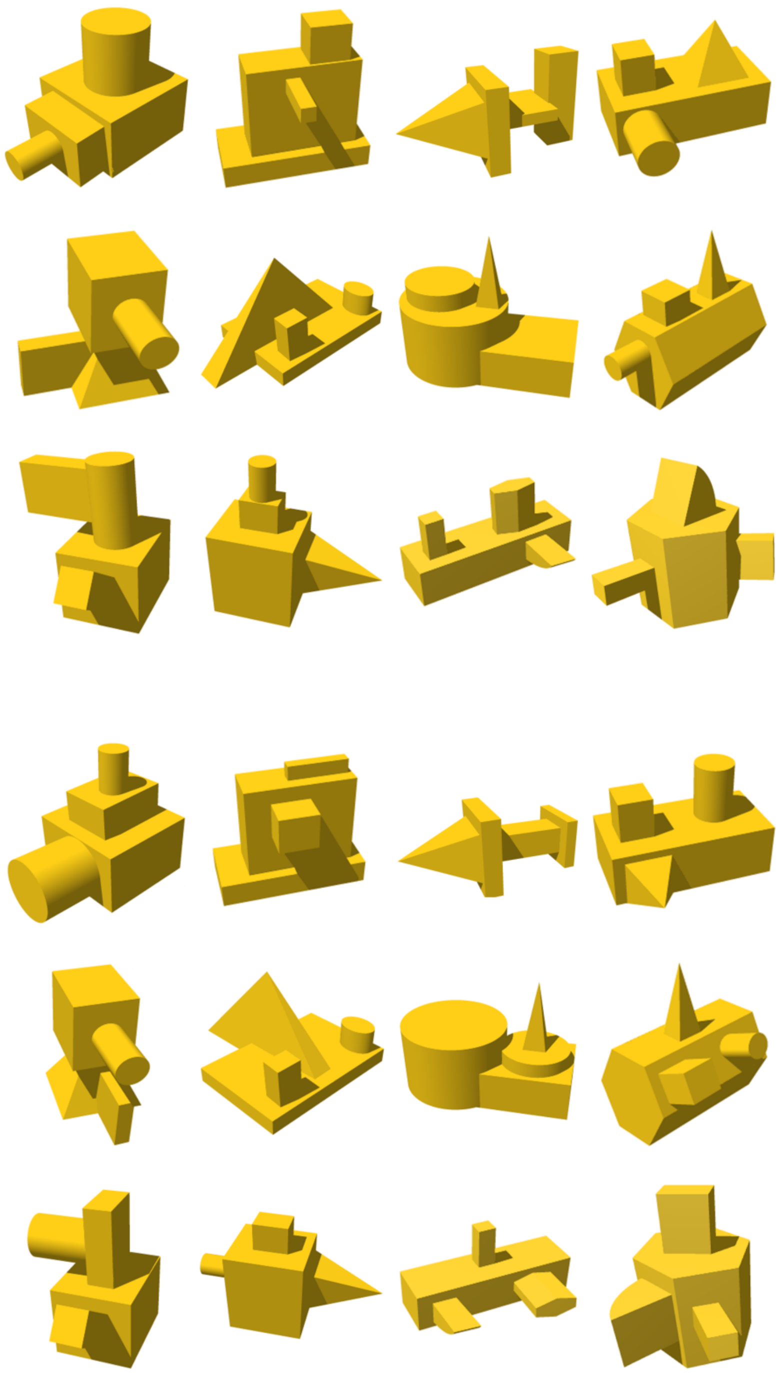
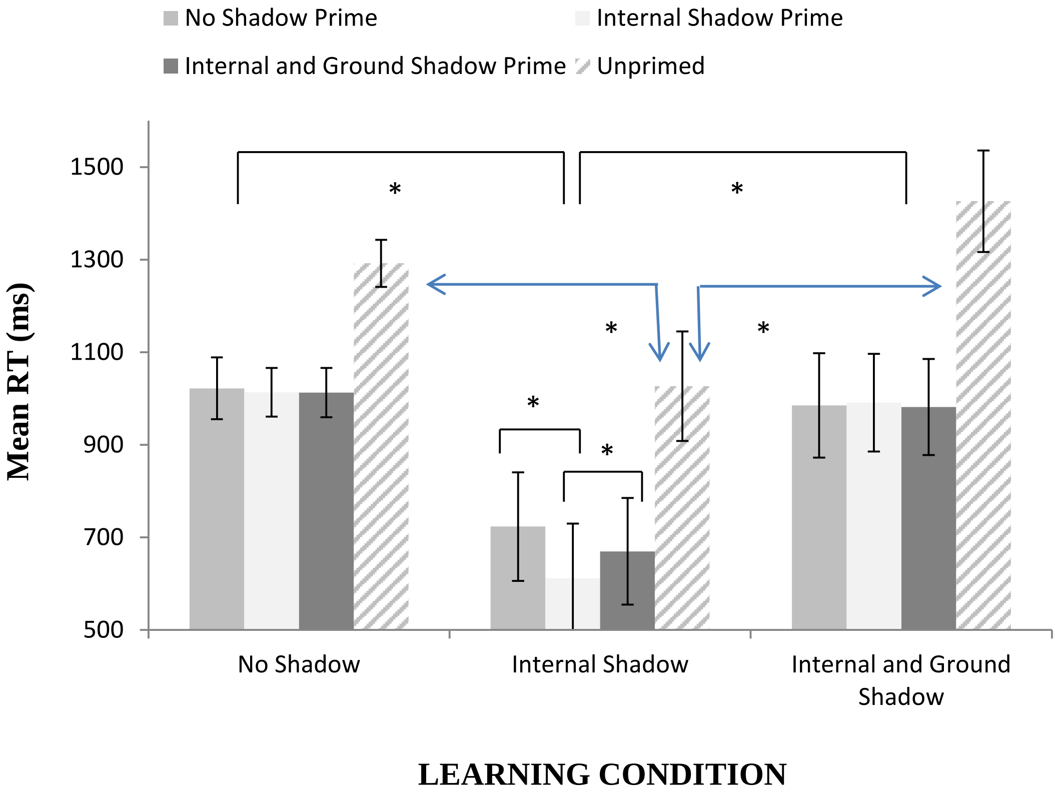


FIGURE 3


No Shadow Prime
Internal Shadow Prime
Internal and Ground Shadow Prime
Unprimed
Mean RT (ms)
1500
1300
1100
900
700
500
*
*
*
*
*
*
No Shadow
Internal Shadow
Internal and Ground Shadow
LEARNING CONDITION